Empirical Research on Science & Technology Innovation Capacity of Universities Based on Data Envelopment Analysis

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Abstract   Universities play an important role in the national innovation system, and the research on the university science & technology innovation capability evaluation is of great significance. DEA method is proposed for the evaluation of university S & T innovation capability, and the main advantage of this method is its ability to accommodate a multiplicity of inputs and outputs. Based on previous studies, this paper builds a comprehensive index system which reflects S & T innovation capacity of universities in China. Empirical analysis is conducted on the universities from 12 provinces and cities by comprehensive use of the index system and DEA method, the result shows that DEA is an instructive option for science & technology evaluation of universities.

Key words   Science & technology innovation capability evaluation; Universities; Data envelopment analysis; Empirical research

1 Introduction

Science & technology evaluation of universities, which can truly reflect the improvement of science & technology comprehensive strength, is center to scientific management of higher education. We can, on one hand, grasp the essence and discipline of scientific innovations in universities; and on the other hand, draw experiences from those innovations. Via the science & technology evaluation, Ministry of Education and universities can formulate S & T policies and deploy public scientific resources reasonably. Scientific management then can be more standardized, scientific and institutionalized.

Data Envelopment Analysis, firstly introduced by Charnes, Cooper and Rhodes in 1978, is a mathematical programming approach to assess relative efficiencies with a group of decision making units [1]. Since the first model of DEA, CCR model, is established, the theory research is further, and the applications increasingly widespread. Thus DEA has become an important and effective analysis tool in the field of management science and engineering. DEA can carry out comprehensive evaluation the relative effectiveness of the same kind of sectors that have multiple input and multiple output. Because of its practicality and without any weight assumptions, in recent years, DEA has been widely used on the evaluation of urban community construction, S&T resource allocation and validity, key disciplines, securities investment funds performance, and other fields. This method is also applied to the evaluation of university building by some domestic scholars. For example, Hou Guangming (2005) used it to evaluate the construction performance of research universities[2], Hou Qipin (2005) used it to evaluate university scientific research performance[3], Huang Chaofeng (2005) applied it to evaluate the efficiency in running the universities[4], Sun Shimin (2007) to evaluate the efficiency on input and output of science research in regional universities[5]. The above studies show it is feasible to evaluate science & technology innovation capacity of universities by DEA. However, except Wang Xiaohong (2004), who applies DEA to the university scientific research performance appraisal[6], few scholars apply it to evaluate science & technology innovation capacity of universities. This is the breakthrough point of this study.

2 Establishment of University S&T Innovation Index

The university science & technology innovation is an organism composed of multi-element. The evaluation on science & technology innovation comprehensively reflects the capability of a university about innovative resources inputs, innovation management, research and development etc., as to comprehensively and scientifically evaluate the science & technology innovation of a university, a scientific index system must be established.

In view of that there has not a systematic and unified science & technology innovation evaluation index system in China currently, on the basis of reference literature [7-10], this paper attempts to build a comprehensive index system which reflects S&T innovation capacity of universities in China.

2.1 Indicators on science & technology inputs

Indicators on Science & Technology Inputs mainly include Human input, teaching and research staff, R&D personnel, financial input, annual science & technology funding, annual research and development expenses, ability of obtain technology projects, number of annual projects, and annual funding for the National Natural Science Foundation. The most active and most important input factor in science & technology system is human. The number and quality of scientists are the importance indicators determined the technological innovation competitiveness. The number of teaching and research staff mainly reflect the base of scientists in this region. Only the amount of the advantage of numbers can make it possible to leap to the quality advantage. R&D personnel indicator reflects the specific number and time of people engaged in scientific research work in the region. Capital investment is the economic base of technology innovation competitiveness Increasing. Science & Technology funds are an important aspect of the scale and level of technology systems, mainly on access to the total annual funding for university science & technology. R&D funding is the basic to ensure sustainable development of the competitiveness of science & technology innovation. Examining the ability to obtain technology projects can indirectly reflect the scale of the scientific and technological manpower, material resources. Usually the obtain of projects indirectly reflect the college or area level of technological innovation. The number of projects can indirectly reflect the region's governments, enterprises and institutions dependent on the university, which reflect the region or university research strength. Evaluation of the National Natural Science Fund is a strict approval procedures and inspection methods. National Natural Science Foundation funding can indirectly reflect the quality of science & technology projects obtained by a region or university, which indirectly reflects the strength of their research.

2.2 Science & technology output indicators

Science & technology output indicators mainly include Number of annual published papers, number of annual foreign published papers, annual monograph number, and number of annual patents results, number of annual achievement awards, and number of annual project assignment. Number of annual published papers is an important achievement of science & technology Innovation, mainly reflecting the number of scientific and technological output. Number of annual foreign published papers are mainly reflects the quality of paper. Monograph is the crystallization of the outcome of years of research scientists. The number of monographs reflects scientific and technological output quantity and quality. The ultimate aim of applied research is applied practice. Number of patents can reflect the actual efficiency of scientific and technological output and technology original capacity level. National Science & technology award is recognition of achievements in science & technology output, in particular the national three awards, the results represent the quality level of technology outputs. The ultimate goal of scientific research is making scientific results in practice. Number of annual project assignment can intuitive express application of science & technology outputs and dissemination of results. The evaluation indicator system of university S&T by DEA methods analysis is showed table 1.

Table 1   The Evaluation Indicator System of University S&T by DEA Methods Analysis

Input indicators	Number of teaching and research staff
	Number of R & D personnel
	Annual science & technology funding
	Annual research and development expenses
	Annual funding for the National Natural Science Foundation
	Number of annual college projects
Output indicators	Number of annual published papers
	Number of annual foreign published papers
	Annual Monograph Number
	Number of annual patents results
	Number of annual achievement awards(the State Council and over, except the provinces technology progress award)
	Number of annual project assignment

3 Empirical Analysis

This paper selects universities which come from 12 provinces and cities such as Heilongjiang, Beijing, Shanghai, Anhui, Shanxi, Tianjin, Zhejiang, Shandong, Guangdong, Liaoning, Hubei, Jiangsu as object, and takes universities in Heilongjiang Province as an example for analysis. The data come

from *college compilation of technology statistical information* (2009) and *Statistics of National Natural Science Foundational Funded projects* (2009) to ensure data's integrity and viability. In this paper, the model we select is the CCR of DEA. The model defines the efficiency of each decision making unit as the ratio of weighted f output and the weighted inputs, through the establishment of linear programming to solve the optimal weights and efficiency values.

This paper mainly explores the CCR model. Suppose that there is a group of n Decision-Making Units (DMUs) and each DMU consists of minputs and soutputs where

$$x_j = (x_{1j}, x_{2j}, \ldots, x_{mj})^T > 0, y_j = (y_{1j}, y_{2j}, \ldots, y_{sj})^T > 0,$$

$x_{ij} = \text{DMU} - j$ and $Y_{rj} = \text{DMU} - j$ refer to the amount of the ith Input and the rth Output, respectively. $(j = 1, 2, \cdots, n; i = 1, 2, \cdots, m; r = 1, 2, \cdots, s)$

Now let us consider the following mathematical programming which can decide the validity and rationality of each DMU.

Where X_0, Y_0, (all positive) are known input and output vectors of the j_0 th DMU and

$$\begin{cases} \max \dfrac{u^T y_0}{v^T x_0} \\ \dfrac{u^T y_j}{v^T x_j} \leq 1, j = 1, 2, \cdots, n \\ u \geq 0, v \geq 0 \end{cases}$$

$v = (v_1, v_2, \cdots v_m)^T, u = (u_1, u_2, \cdots u_s)^T$ (all non-negative) are the variable weight vectors to be determined by the solution of this programming problem.

By using Charnes-Cooper transformation, the above mathematical programming can be changed into the following programming:

$$t = \frac{1}{v^T x_0} > 0, \omega = tv, \mu = tu,$$

$$(P_{C^2R}) \begin{cases} \max \mu^T y_0 = h^0, \\ \omega^T x_j - \mu^T y_j \geq 0, j = 1, 2, \cdots, n, \\ \omega^T x_0 = 1, \\ \omega \geq 0, \mu \geq 0 \end{cases} \qquad (D_{C^2R}) \begin{cases} \min \theta, \\ \sum x_j \lambda_j \leq \theta x_0, \\ \sum y_j \lambda_j \geq y_0, \\ \lambda_j \geq 0, j = 1, 2, \cdots, n, \theta \in E^1 \end{cases}$$

Then $DMU - j_0$ is said to be weak DEA efficient if there exists an optimal solution of (P_{C^2R}) such that $h^0 = 1$. (h^0 is the efficiency of the DMU_0);

$DMU - j_0$ is said to be DEA efficient if there exists an optimal solution (ω_0, μ_0) of (P_{C^2R}) such that $\mu_0 y_0 = 1$ and $\omega_0 > 0, \mu_0 > 0$;

$DMU - j_0$ is said to be DEA efficient only if every optimal solution $\theta^0, \lambda^0{}_j (j = 1, 2, \cdots, n)$ satisfies the condition that

$$\sum_{j=1}^{n} x_j \lambda^0{}_j = \theta^0 x_0, \sum_{j=1}^{n} y_j \lambda^0{}_j = y_0$$

We put above input and output indicators' data into the CCR model. To calculate the decision making unit DMU's relative efficiency and discuss its effectiveness, we need solve a linear programming problem. In order to calculate the relative efficiency of 12 decision-making units, we need solve 12 linear programming problems. So it is a heavy work. This paper selects MATLAB7 software to

solve the linear programming model, and calculated by the program, then gets the composite evaluation value of 12 provinces and cities of scientific technological performance is showed table 2.

Table 2   The Value of θ

DUM	Heilongjiang	Beijing	Shanghai	Anhui	Shanxi	Tianjin
θ	0.8465	1.0000	1.0000	0.8826	1.0000	1.0000
DUM	Zhejiang	Shandong	Guangdong	Liaoning	Hubei	Jiangsu
θ	1.0000	1.0000	1.0000	0.6835	1.0000	1.0000

Table 2 shows that the evaluation value of universities in Heilongjiang province is 0.8465. so we can know the universities' S&T innovation performance in Heilongjiang province is non-technical effective.

To further analyze the question of decision-making unit which did not reach an DEA efficiency, we can use the projection analysis and identify the work we need improve and goals in input and output respects in the process of decision-making units of non-DEA efficient change into DEA efficient, so as to provide a reference information for future management efficiency improvement is showed table 3. It should be noted that the projection analysis can provide goal to improvements, however, this is just explore from the point of view of the best input-output theory. In practice, some of the input index can not be reduced, such as the total number of university teaching and research staff.

So we should formulate improvement measures according to actual situation, then enhance management efficiency, and change in the direction of the DEA efficient. In addition, the selection of evaluation main benefit from data collection, and evaluation of the effectiveness of decision making unit with CCR basic model is relative to the input respects, so its effectiveness is relative.

Table 3   The Projection Analysis of Science & Technology Innovation Performance

Decision making unit	Input indicators	Current input	Target input	Output indicators	Current output	Target output
Colleges in Heilongjiang province	Number of teaching and research staff	10660	8907.49	Number of annual published papers	4262	5100.53
	Number of R & D personnel	2904	2351.37	Number of annual foreign published papers	393	523.06
	Annual science & technology funding	198302	165701.15	Annual Monograph Number	82	98.13
	Annual research and development expenses	136529	114083.63	Number of annual patents results	0	1
	Annual funding for the National Natural Science Foundation	1436	776.88	Number of annual achievement awards	15	20.24
	Number of annual college projects	2055	1717.16	Number of annual project assignment	9	10.77

4 Conclusion

By comparing each indicators, we can know that the size of science & technology innovation of Heilongjiang' universities ranks in the middle level in 12 provinces and cities. In general, the size of science & technology innovation of Heilongjiang' universities is moderate, and keeps pace with the development of Heilongjiang's universities. The performance of university technology performance in Heilongjiang province is non-technical effective, some indicators needs to be improved. Original innovation capacity of the university in Heilongjiang province is weak. Science & technology innovation in Heilongjiang universities has distinctive characteristics in animal husbandry and life sciences, and has a competitive advantage.

Through empirical analysis of 12 provinces' universities of China in science & technology innovation, this paper verifies the feasibility and effectiveness of DEA applied to the evaluation system

of science & technology innovation. This method provides a new way for the evaluation of universities scientific and technological innovation by analyzing and comparing the competitive advantages and disadvantages of universities' science & technology innovation capacity.

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